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Possibilities for reduction of energy consumption by replacing public lighting with LED lighting: case study of Priboj municipality

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ABSTRACT

Electric energy consumed by the public lighting represents a significant item in the city public sector energy consumption structure, which includes public buildings, public transportation and public lighting. Public lighting system is one of the most important public utility activities which is under control of local governments, which pay the costs of electricity, as well as maintenance costs. Public lighting affects the quality of life of citizens in cities through, among other things, reduction of traffic accidents by up to 35%, personal safety and reduction of social approaches.

Cities and municipalities in Serbia are predominately using sodium and mercury bulbs for public lighting, but have been gradually replacing them with LED bulbs in the recent years. LED technology is a satisfactory, cost-effective solution due to low energy consumption, long service life, reduced investment and maintenance costs. Thus, there is not only a reduction in energy consumption of up to 70%, but also a large reduction in CO_2 emissions. The modernization of the public lighting system is, in addition to being a useful means of achieving significant energy savings, also a means of improving the quality of lighting itself.

The paper shows how much it is possible to reduce electricity consumption, and thus CO_2 emissions, by replacing existing lighting with LED lighting. There are 2530 light bulbs in the public lighting system of the municipality of Priboj. Until recently, mercury high pressure bulbs dominated – there were 1241 of them, compared to 743 sodium ones and 546 LED lamps. After the reconstruction of public lighting, all light bulbs are LED. The paper compares the consumption of electricity for the four months of 2019 and the same four months of 2020. It is shown that electricity consumption for these four months was reduced by an average of 55%, the average reduction in CO_2 emissions was 55%, while the reduction in electricity costs was an average of 58%.

KEYWORDS

Public lighting, Energy consumption, Energy saving, Reduction of CO_2 emissions.

1. INTRODUCTION

The possibilities for saving energy in street lighting are very significant, because changes can reduce electricity consumption by more than 50% [1]. By replacing street lighting, in addition to saving energy, visual comfort and safety are improved [2]. One of the most common measures is the replacement of light sources with more efficient LED lamps, which is increasingly becoming a satisfactory and cost-effective solution due to its low energy consumption [3], long life, reduced investment costs [4] and maintenance costs [5], less environmental impact [6] and many other advantages.

In terms of uniformity of street lighting and the comfort it provides, the results show the positive effects of LED street lighting on the surveyed pedestrians and vehicle drivers, as shown by a study conducted for the city of Vienna [7]. When comparing LED lighting and HPS lamps, the results of the analysis for the possibility of improving road lighting standards in Thailand [8], show that the LED lamp has a better energy saving effect than HPS lamp (reduction of energy efficiency index by approximately 40% compared to HPS lamp), which indicates that municipalities and cities benefit from the use of LED lamps. However, although the lighting quality results for LED lamps have values approximately the same as those of the standard ones, the lighting quality needs to be improved in terms of uniformity. In an another research, within the analysis of the optimal lighting solutions characterized by the lowest installed power, it was shown that when considering mesopic effects the average energy savings achieved comparing LED (NW and WW) with HPS lighting solutions amounted to 41–62% and 29–59%, respectively, while the ratio between the total costs of the comparable LED (NW and WW) and HPS lighting solutions belonged to the ranges 0.59–1.26 and 0.61–1.14, respectively. [9] It has also been observed that improvement in areas with poor lighting systems can reduce traffic accidents by up to 35% [10].

The public lighting system is an important municipal function not only because of energy consumption/savings and traffic safety, but also because of its great role in public health and social welfare [11]. Moreover, it is significantly effective in reducing crime and strengthening personal security [12], as well as in overall social well-being [13].

Public lighting also plays a significant role in creating smart cities. The research [14] shows that unlike conventional lighting control systems, that focus only on controlling the lighting levels, the introduced method provides a more effective control solution. The accuracy of this technique is supported by the results of system simulation and implementation. The proposed method is recommended as a novel strategy for meeting the requirements of smart grids, smart cities, and unregulated energy markets.

Also, there is a connection between using two types of warm white and cool white in smart cities [15]. The proposed method benefits from two types of warm white and cool white LEDs and their input power control to adjust the luminous flux and resulting correlated color temperature of light-emitting diodes. The simulation findings confirm the performance of the introduced method. This technique is recommended as a novel strategy, especially to meet the requirements of inhabitants of smart cities.

Public lighting connects hundreds of millions of streetlights with access to power across the globe, being responsible for 19% of global electricity usage, 30% - 50% of a typical city's energy bill and the already exceeding levels of CO_2 emissions [16]. Nowadays, 5.56% of the energy generated in Ecuador is destined to the public lighting service [17]. In Brazil, the public lighting sector is a responsibility of the municipal government and typically represents around 4% of the electricity consumed by cities [18].

In Serbia, as well as in the surrounding countries, costs for public lighting in municipal/city budgets are a significant item – the public lighting in the city of Rijeka, in Croatia, for example, takes about 3% of total electricity consumption in the city, which is a significant cost for municipal budgets [19].

Due to all the above, it is necessary to replace outdated street lighting with modern LED lighting. However, the improvement and modernization of public lighting systems in cities and municipalities is often hampered by high perceived investment risks, long payback periods and a lack of capacity for local governments to implement these projects themselves. At the municipal level, these issues are particularly pronounced because the procurement, implementation and management of retrofitting may exceed existing municipal management capacities. Therefore, public-private partnership is emerging as one of the solutions for improving the public lighting system and energy efficiency in cities and municipalities [20].

2. PRIBOJ MUNICIPALITY CASE STUDY

2.1. Electric Power Consumption in Public Sector

Electricity consumption in the public sector includes electricity consumption in public buildings and public lighting. The analysis of consumption in the period of four years (2016-2019) shows that the share of electricity consumption for public lighting was 60% higher than the share of electricity consumption in public buildings.

During the 2016 and 2017, electricity consumption in public buildings in Priboj municipality was 1,092,579 kWh and 1,136,660 kWh, respectively, while electricity consumption in public lighting was 1,644,541 kWh and 1,610,204 kWh, respectively. In 2018 and 2019, electricity consumption in the public sector in Priboj municipality was a little less. Public buildings electricity consumption in 2018 and 2019 was 1,099,518 kWh and 1,137,884 kWh, respectively (slightly increased, compared to the previous two years), while electricity consumption in public lighting was significantly reduced, i.e. 1,306,939 kWh and 1,306,048 kWh, respectively.

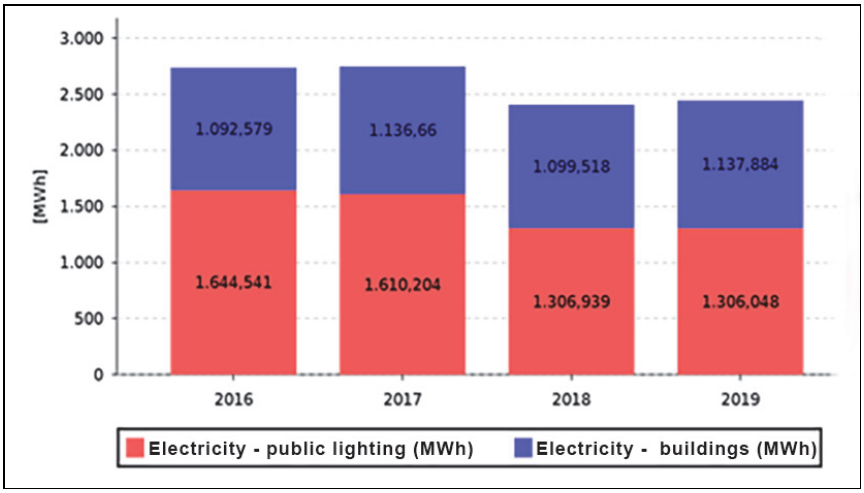

Figure 1: Structure of electricity consumption in the public sector before lamp replacement

2.2. Previous situation in public lighting

The main characteristics of the public lighting system in the municipality of Priboj were mostly inefficiency and obsolescence, and as such, the system did not provide quality lighting. There were high costs for energy and maintenance. In addition, the function of the system was significantly impaired by years of insufficient or poor maintenance.

The maintenance of the public lighting system carried out by the municipality included the replacement of light sources (bulbs) and other parts of lamps (ballasts, bulb sockets, glass protectors), replacement of damaged lamps, replacement of damaged poles and cable installations, replacement of damaged parts of control units (meters, contactors, photo relays, astronomical clocks, fuses) and, if necessary, system expansion.

Table 1: Condition of lamps before replacement

STRUCTURE OF LAMPS	NUMBER OF LAMPS	INSTALLED POWER (in kW)
Mercury 125M	998	137.23
Mercury 250M	243	66.83
Sodium 70M	595	45.82
Sodium 100M	36	3.96
Sodium 150M	33	5.45
Sodium 250M	48	13.20
Spotlight MX 30	1	0.03
Spotlight MX 150	10	1.65
Spotlight MX 250	4	1.10
Spotlight MX 400	2	0.88
Spotlight HA 250	4	1.10

Spotlight HA 400	10	4.40
Existing LED 28	64	1.79
Existing LED 39	57	2.22
Existing LED 57	152	8.66
Existing LED 84	202	16.97
Existing LED 110	20	2.20
Existing LED spotlight 50	7	0.35
Existing LED spotlight 100	16	1.60
Existing LED spotlight 400	28	11.20
TOTAL:	**2,530**	**326.62**

On the whole, the quality of maintenance of the public lighting system was insufficient, which resulted in insufficient quality of the lighting itself. This situation endangered the safety of all participants in traffic, and the problem of inadequate lighting particularly posed the problem for the traffic safety of children - pedestrians.

Table 1 shows the condition of the lamps before the replacement of the bulbs - the total number of lamps and the total installed power.

Figure 2 represents the percentage structure of public lighting in the municipality of Priboj. As it can be seen, the existing lighting was dominated by mercury bulbs with 49.05% and sodium bulbs with 28.14%.

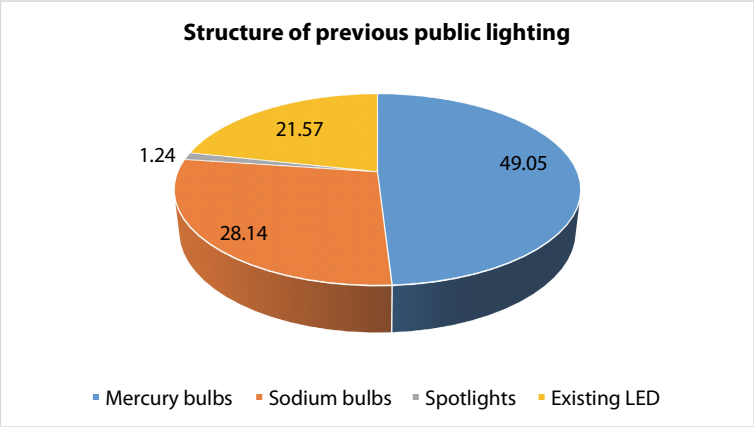

Figure 2: Structure of public lighting before light bulb replacement

2.3. Improved condition

When drafting the reconstruction proposal and finding the optimal lighting solution, the following principles were followed:

- to rely on the existing electrical installation for the solution,
- to propose a rational solution that meets the necessary lighting criteria relating to a given category of road, to the extent that the current network infrastructure allows it,
- to meet the required levels of illumination with adequate installed equipment, meaning that it is necessary to use the highest quality lamps and to meet the applicable standards and regulations regarding the illumination of roads.
- to significantly reduce electricity consumption.

In addition to the choice of lamps, it is important to consider the method of managing the public lighting system. The following results are achieved by managing public lighting:

- reduction of energy consumption and CO_2 emissions,
- reduction of light pollution,
- reduction of maintenance costs.

By installing an appropriate control system, it is possible to provide night control of lighting and reduce the intensity of light emitted by each lamp, while maintaining uniformity of illumination. There are different systems for managing

public lighting. The most economical way to regulate night lighting is through built-in automatic dimmers in the lamps. It is a tested technology that has been functioning reliably for many years. The rate of failures in newly installed luminaires is minimal and they are eliminated by a private partner during the term of the contract.

The analysis of the data obtained by field measurements, which are shown in Table 1, established the exact number of lamps that are the subject of reconstruction and calculated the exact installed power. When choosing new lamps, it was made sure that they have good photometric characteristics, a high degree of mechanical and electrical protection, made of quality and unbreakable materials, which ensures a long service life.

During the public-private partnership, the private partner prepares project documentation, procurement, transport and installation of equipment, managing the replacement of existing lamps for energy efficient LED lamps, disposal of old equipment in a place determined by the public partner, financing, insurance (in the first year) and maintenance of the project and public lighting system for the duration of the contract, with the aim of reducing budget costs and raising the level of efficiency in the provision of public services. The project is fully financed from the potential of a private partner - there are no investments for local self-government.

The analysis of the categorization of roads and the number of existing luminaires determined the exact number of LED luminaires needed for the reconstruction of public lighting and their installed power. Based on these principles, Table 2 shows the newly designed solution.

Table 2: Condition of lamps after replacement

Type of lamp and its power (W)	Total Number	Total Installed Power in (kW)	Total dimmed installed power in (kW)
NEW LED 80 W	99	7.92	6.73
NEW LED 60 W	359	21.54	18.31
NEW LED 45 W	17	0.77	0.65
NEW LED 40 W	994	39.76	33.8
NEW LED 25 W	484	12.1	12.1
NEW REF 60 W	11	0.66	0.66
NEW REF 100 W	20	2.00	2.00
LED REF 50 W*	7	0.35	0.35
LED REF 100W*	16	1.6	1.6
LED REF 400W*	28	11.2	11.2
LED LAMP.28W*	64	1.79	1.79
LED LAMP 39W*	57	2.22	2.22
LED LAMP 57W*	152	8.66	8.66
LED LAMP 84W*	202	16.97	16.97
LED LAMP 110W*	20	2.2	2.2
TOTAL	**2530**	**129.74**	**119.24**

Estimated financial savings:

After the reconstruction, the Municipality of Priboj in the first year should achieve guaranteed savings of at least 1389293 RSD or 11675 EUR, which is 10% of current expenditures on the electricity bill annually. The estimated financial savings during the 15-year contract should reach about 26 million RSD for the Municipality of Priboj (in case there is no increase in electricity prices in the next 15 years, which is unlikely).

3. ACHIEVED SAVINGS

Table 3 shows electricity consumption and energy savings for public lighting in the municipality of Priboj, in 2019 and 2020.

Table 3: Savings in electricity consumption

Period	Electricity consumption for public lighting in 2019 (kWh)
September 2019	97,129
October 2019	136,984
November 2019	128,850
December 2019	148,365
TOTAL ELECTRICITY CONSUMPTION IN 4 MONTHS OF 2019 (kWh)	**511,328**

Period	Electricity consumption for public lighting in 2020 (kWh)
September 2020	44,017
October 2020	57,052
November 2020	60,392
December 2020	70,718
TOTAL ELECTRICITY CONSUMPTION IN 4 MONTHS OF 2020 (kWh)	**232,179**
Period	Electricity savings (kWh)
September 2020	53,112
October 2020	79,932
November 2020	68,458
December 2020	77,647
TOTAL ELECTRICITY SAVINGS (kWh)	**279,149**
Period	Electricity savings (%)
September 2020	55
October 2020	58
November 2020	53
December 2020	52
AVERAGE ELECTRICITY SAVINGS (%)	**55**

Savings in electricity consumption amount from 53 112 kWh to a maximum of 79 932 kWh, which is a percentage of 52-58%, an average of 55% for the four analyzed months. Figures 3 shows the graphical presentation of reduction of electricity consumption for public lighting, for the analyzed period (September 2019-December 2020).

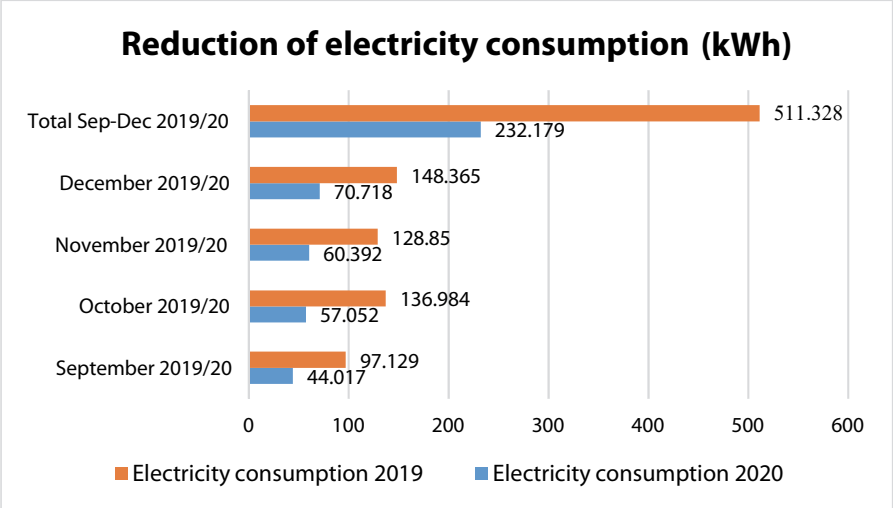

Figure 3: Reduction of electricity consumption – comparison between previous and new public lighting system

Table 4 shows reduction of CO_2 emission for public lighting in the municipality of Priboj, for the period from September 2019 to December 2020.

Table 4: CO_2 emission savings

Period	CO_2 emission in 2019 (tCO_2)
September 2019	106.84
October 2019	150.68
November 2019	141.74
December 2019	163.20
TOTAL CO_2 EMISSION IN 4 MONTHS OF 2019 (tCO_2)	**562.46**
Period	CO_2 emission in 2020 (tCO_2)
September 2020	48.42
October 2020	62.76
November 2020	66.43
December 2020	77.79

TOTAL CO_2 EMISSION IN 4 MONTHS OF 2020 (tCO_2)	**255.40**
Period	CO_2 emission reduction (tCO_2)
September 2020	58.42
October 2020	87.93
November 2020	75.30
December 2020	85.41
TOTAL CO_2 EMISSION REDUCTION (tCO_2)	**307.06**
Period	CO_2 emission reduction (%)
September 2020	55
October 2020	58
November 2020	53
December 2020	52
AVERAGE CO_2 EMISSION REDUCTION (%)	**55**

Results, obtained after installing the new LED lamps, in analyzed period, show the reduction in CO_2 emissions in range from 58.42 tCO_2 to 87.93 tCO_2. As a percentage, the reduction in CO_2 emissions is up to 52 to 58%, which is an average of 55%.

Figure 4 shows reduction of CO_2 emissions in a case of municipality of Priboj, after installing LED lamps, for the same period as electricity consumption (from September 2019 to December 2020). It can be concluded that a significant reduction in CO_2 emissions is achieved with new LED lamps, compared to the previous system of public lighting with dominant mercury bulbs and sodium bulbs.

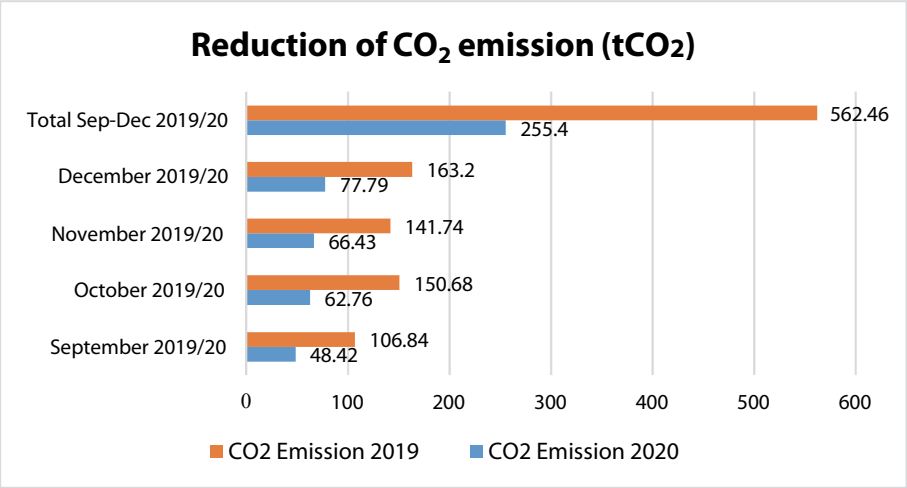

Figure 4: Reduction of CO_2 emissions - comparison between previous and new public lighting system

Table 5 shows electricity cost reductions, obtained with LED lamps in the municipality of Priboj, for the period from September 2019 to December 2020.

Table 5: Savings in electricity costs

Period	Cost of electricity for public lighting in 2019 (RSD)
September 2019	1,136,164.47
October 2019	1,604,476.30
November 2019	1,508,681.19
December 2019	1,737,011.62
TOTAL ELECTRICITY COSTS IN 4 MONTHS OF 2019:	**5,986,333.58**
Period	Cost of electricity for public lighting in 2020 (RSD)
September 2020	471,923.17
October 2020	611,085.91
November 2020	646,711.74
December 2020	757,052.07
TOTAL ELECTRICITY COSTS IN 4 MONTHS OF 2020:	**2,486,772.89**

Period	Savings in electricity costs for public lighting (RSD)
September 2020	664,241.30
October 2020	993,390.39
November 2020	861,969.45
December 2020	979,959.55
TOTAL SAVINGS IN ELECTRICITY COSTS:	**3,499,560.69**
Period	Savings in electricity costs for public lighting (%)
September 2020	58%
October 2020	62%
November 2020	57%
December 2020	56%
AVERAGE SAVINGS IN ELECTRICITY COSTS	**58%**

Savings in electricity costs on a monthly basis amount to 664,241.30 to 979,959.55 dinars. As a percentage, savings range from 56 to 62%, averaging 58% on a monthly basis compared to the same period previous year.

Figure 5 shows the structure of electricity consumption in the last five years and shows that the share of electricity consumption for public lighting was 60% higher than the share of electricity consumption in public buildings in 2016, and in 2020 consumption was higher for public buildings than for public lighting.

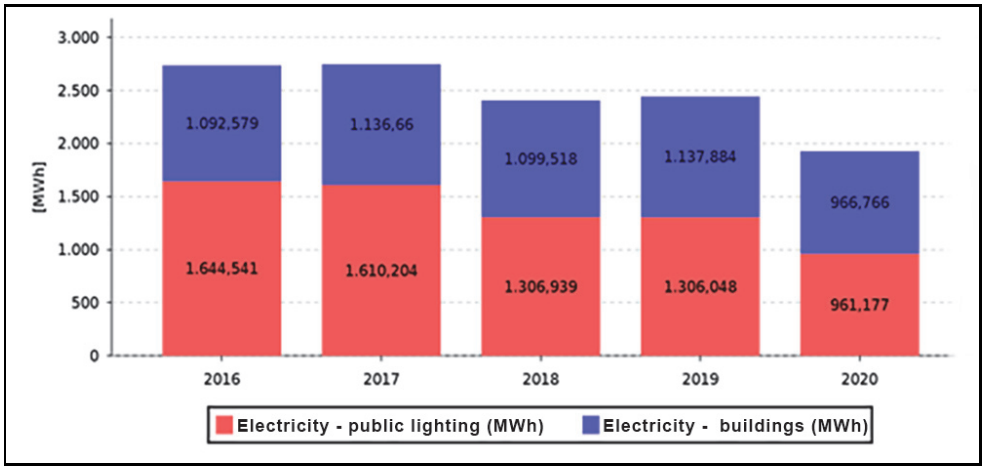

Figure 5: Structure of electricity consumption in the public sector before and after lamp replacement

4. CONCLUSION

The replacement of existing light sources with more efficient LED lamps is increasingly becoming a satisfactory and cost-effective solution due to its low energy consumption, long life, improved quality of lighting, and thus increased general safety and satisfaction of citizens, reduced investment and maintenance costs, lower environmental impact and many other benefits. Better quality of life of citizens is achieved through greater safety in traffic, both for pedestrians and drivers, and by reducing the number of traffic accidents. New LED lighting also affects general security, reduces social crime and strengthens personal security. In addition, new LED lighting contributes to the creation of smart cities. At the same time, as it is a public-private partnership project, quality maintenance by a private partner and quality management of the public lighting system is achieved.

This paper represents the possibility for reduction of electricity consumption and thus CO_2 emissions, by replacing existing lighting with LED lighting, in a case of public lighting system of the municipality of Priboj. The savings achieved are: reduction of electricity consumption in four months period by an average of 55%, average reduction of CO_2 emissions by 55%, while reduction of electricity costs is averagely 58%. These results clearly show the importance of replacing obsolete public lighting devices with new ones, both in terms of energy saving and emission reduction, as well as in financial term.

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